International Journal of Electrical and Electronics
Engineering Research (IJEEER)
ISSN(P): 2250-155X; ISSN(O): 2278-943X
Vol. 3, Issue 5, Dec 2013, 127-132

PERFORMANCE OF SIMPLE BOOST CONTROLLED Z SOURCE INVERTER FED THREE PHASE LOCOMOTIVES IN THE MOTORING REGION

VASANTHI V[1] & ASHOK S[2]

[1]Research Scholar, Electrical Engineering Department, National Institute of Technology, Calicut, Kerala, India

[2]Professor, Electrical Engineering Department, National Institute of Technology, Calicut, Kerala, India

ABSTRACT

Electric traction system uses voltage source inverter technology for three phase electric locomotives. This paper proposes Z source inverters to control the speed of locomotive drives. The acceleration region and free running region of operation of locomotive is considered for analysis. The control strategy for Z source inverter used is simple boost control. The speed control method for traction motors is variable voltage variable frequency in the constant torque mode and field weakening in the constant power mode of operation. The front end converter of the locomotive is controlled so as to provide constant dc voltage and keep the input power factor unity. The use of Z source inverter reduced the dc link voltage of the locomotive and also the average total harmonic distortion in the inverter output voltage.

KEYWORDS: Locomotive, Z Source Inverter, Electric Traction, Simple Boost Control

INTRODUCTION

Electric locomotives can be classified into two category, dc and ac locomotives. AC locomotives use three phase induction motors for main line services now a days. The locomotive circuit consists of ac-dc converter and voltage source inverter (VSI) fed three phase induction motors. The front end converter is capable of maintaining constant dc voltage and keeping the input power factor at unity. Reference [1] provides control circuits for keeping the power factor of the converter constant at unity and making the current controller faster. An H bridge front end converter for electric multiple units is proposed which improves the total harmonic distortion and maintains the power factor at unity [2]. An inverter is presented which has the capability of buck or boost converter namely Z source inverter (ZSI) which uses simple boost control topology [3]. The Z-source converter overcomes the conceptual and theoretical barriers and limitations of the traditional voltage-source converter and current-source converter and provides a novel power conversion concept. Different control topologies for Z-source inverter have been presented [4-6]. Z-source inverter fed by diode rectifier is applied to general purpose drives which reduces line harmonics and improves power factor [7].

To enhance the performance in the low speed range of current fed inverter drive, an LC network is proposed to couple the inverter main circuit to the diode front end [8]. Reference [9] presented the application of Z-source inverter for fuel cell-battery hybrid electric vehicle. Modeling of a Z-source converter, control system and implementation of modified space vector PWM (MSVPWM) has been reported in reference [10]. A comparative analysis of different types of converters fed from fuel cells in the medium power range has been reported [11]. Reference [12] presents the application of bidirectional Z source inverter for automotive applications such as hybrid electric vehicle (HEV), plug-in hybrid electric vehicle (PHEV), for fuel cell hybrid electric vehicles (FCHEV). Adjustable speed drives system with partly PAM/PWM control strategy, which consists with the V/f law, is presented in [14] which eliminates the DC-link voltage aberrances, and increase the inverter modulation index.

In this paper, z source inverter in the simple boost control method is proposed for locomotive drives. The speed control method adopted is variable voltage variable frequency with constant dc input to the inverter. The constant torque and field weakening mode of operation of locomotive is analyzed. The front end converter maintains the dc output at constant value and keep the input power factor unity.

SYSTEM MODEL

The system consists of a locomotive transformer which receives single phase 25kV ac supply through the pantograph of locomotive and steps down the voltage to a lower value. The transformer has got four secondary windings called traction windings. A four quadrant ac –dc converter is connected to each of the traction windings. The output of the two converters is connected in interleaved fashion to a dc link capacitor. There are two inverters fed by each of the two dc link capacitors. Each of the inverters act as source to three parallel connected induction motors. The demand of the locomotives is met by six traction motors.

The equation for single phase system [1] is given in (1)

$$V_s\,(t) = L_s \frac{di_s(t)}{dt} + V_r(t) \tag{1}$$

where Vs(t) is the transformer secondary voltage, Ls is the leakage inductance, Vr(t) is the converter input voltage, m is the modulation index, Vdc represents the dc link voltage.

$$V_r = m\,V_{dc} \tag{2}$$

If the dc link voltage is constant, from the power balance equation

$$I_s \cos\varphi = V_r \sin\frac{\delta}{X_s} \tag{3}$$

$$I_s \cos\varphi = \frac{Vs - Vr\cos\delta}{X_s} \tag{4}$$

Where Is represents the source current, φ is the power factor angle, δ is the angle between Vs and Vr. For unity power factor the reactive power drawn must be zero. Under full load condition, the leakage reactance Xs can be determined from equations (2) and (3). The block diagram of proposed locomotive is given in figure 1.

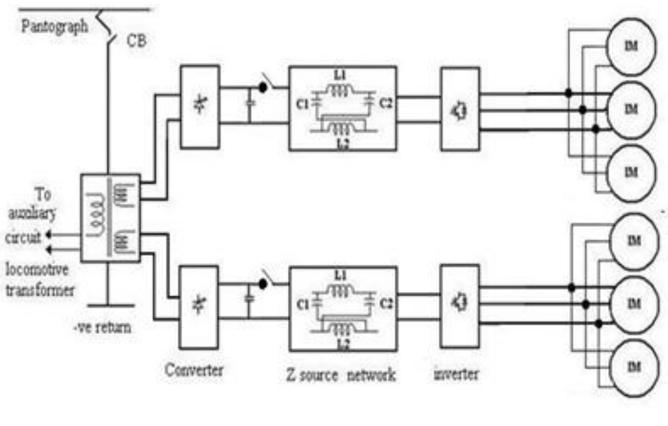

Figure 1: Block Schematic of Z Source Inverter Fed Locomotive Drive

The matrix differential equation of induction motor described in stator reference frame model [13] is given by equation (5)

$$\begin{bmatrix} V_{qs} \\ V_{ds} \\ V_{qr} \\ V_{dr} \end{bmatrix} = \begin{bmatrix} R_s + L_s p & 0 & L_m p & 0 \\ 0 & R_s + L_s p & 0 & L_m p \\ L_m p & -\omega_r L_m & R_r + L_r p & -\omega_r L_r \\ \omega_r L_m & L_m p & \omega_r L_r & R_r + L_r p \end{bmatrix} \tag{5}$$

$$T_e = \frac{3}{2}\frac{P}{2} L_m \left(i_{qs} i_{dr} - i_{ds} i_{qr} \right) \tag{6}$$

Where Rs and R_r represents the stator and rotor resistances, L_s, L_r and L_m are the stator, rotor and magnetizing inductances, p indicated the differential operator d/dt, ω_r the speed of rotor in rad/s. V_{qs}, V_{ds}, V_{qr}, V_{dr} represents the quadrature and direct axes voltages of stator and rotor respectively, i_{qs}, i_{ds}, i_{qr} and i_{dr} are the quadrature and direct axes currents of stator and rotor respectively. The electromagnetic torque is given by equation (6) where P represents the number of poles.

DESIGN OF Z SOURCE NETWORK PARAMETERS

The impedance network of Z source inverter [15] is calculated by using the equations given by (7) and (8).

$$L_1 = L_2 = L = \frac{V_o T (2V_{ac} - V_o)}{2k_i\, I_o (4V_{ac} - V_o)} \tag{7}$$

$$C_1 = C_2 = C = \frac{I_o T (2V_{ac} - V_o)}{2k_v V_o (4V_{ac} - V_o)} \tag{8}$$

Where V_{ac} is the peak phase output voltage of the inverter, V_o is the input To is the shoot through interval over a switching cycle T, B is the boost factor.

CONTROL TOPOLOGY

The front end converter uses the sine pwm method of control for generating pulses. The output dc voltage of the converter is maintained at constant value in both types. The z source inverter uses the simple boost control method of triggering. The switching frequency of converter and inverter is kept a low value because of the high power nature of the load. There are different modes of operation for a locomotive drive namely constant torque mode, constant power mode and regenerative braking mode. In this work only motoring operation is considered. The control strategy for speed control of the motor in constant torque mode is open loop variable voltage variable frequency with constant v/f ratio depending on the demand from driver's cabin. This region is the accelerating part of the traction curve. The constant power mode is used in high speed region of locomotive which requires less torque compared to the accelerating region. Voltage is kept at its rated value and only frequency is varied in this region. Torque is varied inversely with frequency and switching frequency is selected as three times the fundamental frequency in order to reduce the torque ripple.

The front end converter output dc voltage of Z source inverter is kept at 1700 V. In the case of Z source inverter, two control topologies are adapted for the constant torque region for low frequency region and high frequency region. The shoot through pulses is not considered in the low frequency region since the available dc link voltage is enough to provide the required voltage to the traction motors. As the machine accelerates, the shoot through pulses is introduced to provide a boost in the inverter output voltage. The modulation ratios for low frequency and high frequency regions are decided by the equations (9) and (10) respectively.

$$\widehat{V_{LL1}} = M\frac{V_o}{2} = f * \left(\frac{v}{f}\right)\sqrt{2}/\sqrt{3} \tag{9}$$

$$\widehat{V_{ac}} = MB\frac{V_o}{2} = f * \left(\frac{v}{f}\right)\sqrt{2}/\sqrt{3} \quad (10)$$

Where f=frequency of motor, $\hat{V}_{ac}$ is the peak value of stator voltage per phase. The relation between shoot through duty ratio and modulation index and the boost factor [3] for simple boost control are given in equation (11) and (12) respectively.

$$D_o + M \leq 1 \quad (11)$$

$$B = \frac{1}{1-2\frac{T_o}{T}} \quad (12)$$

Where M is the modulation index, B is the boost factor, $D_o = \frac{T_o}{T}$ is the shoot through duty ratio, T_o is the shoot through period during a switching cycle T. In the field weakening, M is kept constant at a higher value than unity and shoot through duty ratio is adjusted to get the required voltage and speed. The voltage is kept constant and frequency is varied as in the previous case. The selection of switching frequency and torque are the same as in voltage source inverter drive.

SIMULATION RESULTS

The simulation results for z source inverter fed drive with open loop v/f law are plotted in figure 2 to figure 8. The frequency is changed at t=1.5s, 2.5s, 3.5s, 5.5 s and t=7s. At t=7s, the frequency is above the base value and motor is in the field weakening mode. The dc link voltage is reduced to 1700V in zsi fed drive as compared to 2800V in existing voltage source inverter fed drive. This can reduce the magnetic losses in the drive. The average value of total harmonic distortion of stator voltage and stator current are tabulated in table.1.

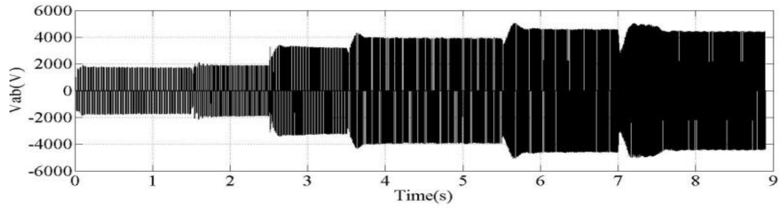

Figure 2: Inverter Output Voltage for ZSI

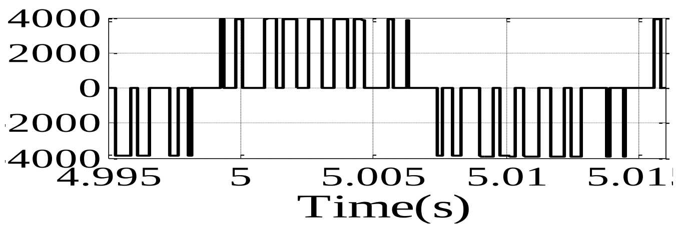

Figure 3: Detailed View of Inverter Output Voltage

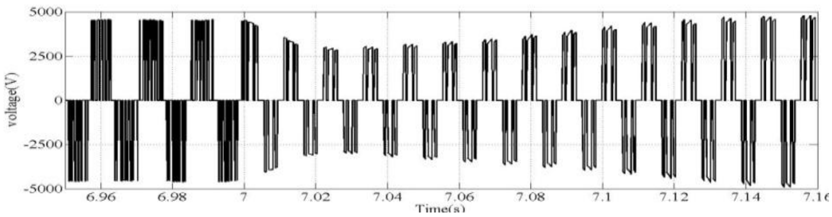

Figure 4: Inverter Output Voltage Entering into the Field Weakening Mode

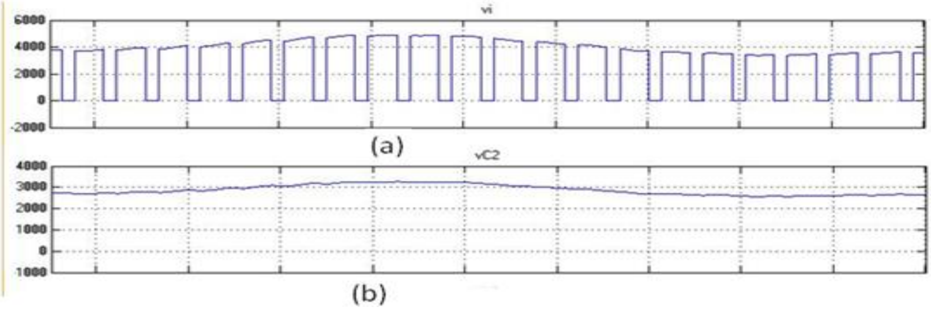

Figure 5: Detailed View of (A) Dc Link Voltage, (B) Capacitor Voltage

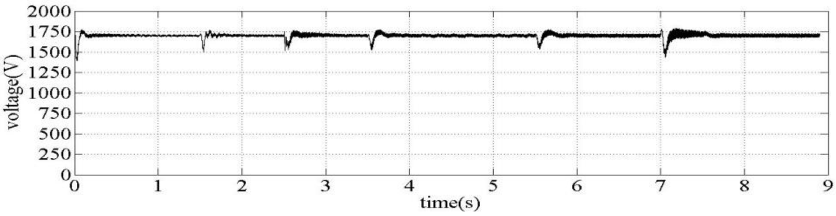

Figure 6: Input Dc Voltage to ZSI

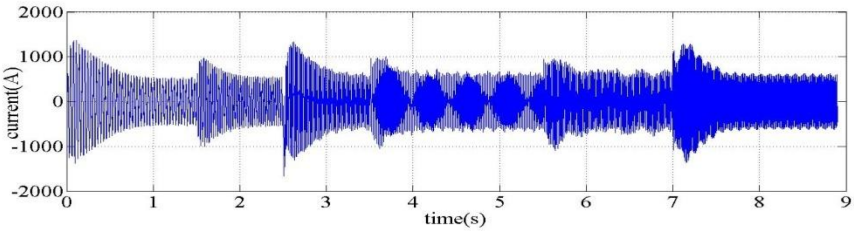

Figure 7: Current Drawn by Traction Motors

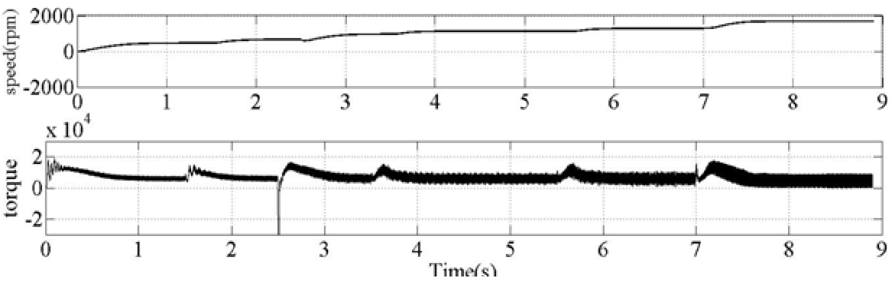

Figure 8: (A) Speed of Motor and (B) Torque Developed

Table 1: Total Harmonic Distortion at the Inverter Output Voltage and Current

Parameter	ZSI Fed Loco
Average THD of inverter output voltage (%)	89.98
THD I of stator current (%)	14.3

CONCLUSIONS

Three phase locomotive drives with Z source inverter technology is modeled and simulated in MATLAB. The two regions of operations constant torque and constant power mode are considered for performance investigation. Simple boost control is used for generating pulses for Z source inverter. The speed control of the traction motor is variable voltage variable frequency in the constant torque mode and field weakening in constant power mode. The dc link voltage can be reduced in case of ZSI technology. The reduction of dc link voltage results in reduction of cost of capacitor at the dc link thereby reducing the overall cost of the system.

ACKNOWLEDGEMENTS

The authors acknowledge the Indian railway for the permission for data collection and measurement.

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APPENDIX

Motor Parameters:

Power: 1150kW; Frequency:80Hz; Voltage 2180 V; Current 370A; pf 0.86; speed 1585 rpm